	L #	Hits	Search Text	DBs	Time Stamp
1	L1	2163	magnetic adj loss	US-PGPUB; USPAT; EPO; JPO; DERWENT; IBM_TDB	2005/05/25 09:19
2	L2	31	1 and M-X-Y	US-PGPUB; USPAT; EPO; JPO; DERWENT; IBM_TDB	2005/05/25 09:22
3	L3	0	2 and ((@ad<"20000404") or (@rlad<"20000404"))	US-PGPUB; USPAT; EPO; JPO; DERWENT; IBM_TDB	2005/05/25 09:22
4	L5	85	1 and granular	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	2005/05/25 09:22

	L #	Hits	Search Text	DBs	Time Stamp
5	L6	30	5 and ((@ad<"20000404") or (@rlad<"20000404"))	US-PGPUB; USPAT; EPO; JPO; DERWENT; IBM_TDB	2005/05/25 09:23
6	L7	3	("6069820").PN.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	2005/05/25 10:11
7	L8	0	1 and 7	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	2005/05/25 10:12
8	L9	8	(("6648990") or ("20040048092") or ("6069820") or ("20020189718")).PN.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	2005/05/25 10:13

	L #	Hits	Search Text	DBs	Time Stamp
9	L10	4	9 and granular	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	2005/05/25 10:13
10	L11	1	10 and "saturation magnetization"	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT; IBM_TDB	2005/05/25 10:14

US-PAT-NO: **6069820**

DOCUMENT-IDENTIFIER: US 6069820 A

TITLE: Spin dependent conduction device

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US Patent No. - PN (1):
6069820

Brief Summary Text - BSTX (6):
A metal artificial lattice film which exhibits a giant magnetoresistance effect (GMR) was reported in publications, 61 Phys. Rev. Lett., 2472(1988), 94 J. Mag. Mater., L1(1991), and 66 Phys. Rev. Lett., 2152(1991). The film comprises a plurality of ferromagnetic layers and nonmagnetic layers interposed between each of the ferromagnetic layers. The electrons scattering characteristic in the film depends on spin directions of ferromagnetic layers of the film. The film has about a 10 or 20% MR amplitude. Many layers are needed to obtain a high MR amplitude, and the **saturation magnetization** is as much as several Tesla (T). These characteristics are not preferable for applying the film to the magnetic head.

Brief Summary Text - BSTX (9):
It was reported that the GMR could be obtained by using a **granular** ferromagnetic film. The film comprises dispersed magnetic fine-grains in a nonmagnetic metal material layer as reported in 68 Phys. Rev. Lett., 3745(1992). Spins of the fine-grains have mutually irregular directions, and the film shows high resistance with no applied field. When the magnetic fields are applied, the resistance of the film decreases. The fine-grains have super-paramagnetism and large **saturation magnetization** fields.

Brief Summary Text - BSTX (12):
Other tunnel junctions having Al.sub.2 O.sub.3 **/granular** layer/Al.sub.2 O.sub.3 were also reported in R56 Phys. Rev., R5747 (1997). The

granular layer
comprises Co grains formed in an Al.sub.2 O.sub.3 material. Each of the Co grains has a diameter of several nanometers, does not have uni-direction and shows paramagnetic at 120.degree. K. Therefore, the **granular** layer does not spin switch at low temperature even though it is provided with a large magnetic field of more than 0.5 Tesla and the device does not show spin resonance tunnel effect.

Brief Summary Text - BSTX (32):
In the present invention, the magnetic device may have 30% or more MR amplitude at room temperature, where the magnetoresistance amplitude is defined by .DELTA.R/Rs, where .DELTA.R is resistance change of the device and Rs is a device resistance at **saturation magnetization** fields.

Drawing Description Text - DRTX (5):
FIG. 4 is a schematic cross-sectional view showing a magnetic device having a **granular** layer according to a second embodiment of the present invention.

Drawing Description Text - DRTX (6):
FIG. 5 is a schematic cross-sectional view showing a magnetic device having a multiple **granular** layer structure according to the second embodiment of the present invention.

Drawing Description Text - DRTX (7):
FIG. 6 is a schematic cross-sectional view showing another magnetic device having a multiple **granular** layer according to the second embodiment of the present invention.

Detailed Description Text - DETX (9):
The tunnel current flows based on the spin polarization tunnel effect are also obtained via the discrete energy level formed in a ferromagnetic **granular** layer. The **granular** layer has a grain or a plurality of grains in a nonmagnetic material. The grain size is small enough to have spin split

discrete energy levels in itself. A 30% MR amplitude or more based on the spin polarization tunnel effect is obtained by using a **granular** layer at room temperature.

Detailed Description Text - DETX (15):

FIG. 4 shows a schematic cross-sectional view of a magnetic device having a **granular** layer according to a second embodiment of the present invention.

Detailed Description Text - DETX (16):

The magnetic device comprises a first metal layer 11, a first dielectric layer 12, a **granular** layer 16, a second dielectric layer 14, and a second metal layer 15. The first metal layer 11 may be formed of a ferromagnetic material. The second metal layer 15 may be formed of a ferromagnetic material or a nonmagnetic material. The **granular** layer 16 comprises a plurality of ferromagnetic grains 18 scattered in a dielectric material material 17. For simplicity, only two ferromagnetic grains 18 are shown in FIG. 4. Alternatively, the **granular** layer 16 may have one ferromagnetic grain 18. The ferromagnetic grains do not have super-paramagnetism and have finite coercive force. The grain size of the ferromagnetic grains 18 may be different from each other. Preferably the grains are divided by the dielectric layers 12, 14 and have a small grain size.

Detailed Description Text - DETX (19):

FIG. 5 is a schematic cross-sectional view showing a magnetic device having a multiple **granular** layer structure according to the second embodiment of the present invention. The magnetic layer 16 may be substituted with a plurality of ferromagnetic layers 16a, 16b, 16c, and a plurality of dielectric layers 14a, 14b, 14c interposed between the magnetic layers, as shown in FIG. 5, so as to form multiple tunnel junctions. Each of the ferromagnetic layers 16a, 16b, 16c comprises ferromagnetic grains 18 scattered in the dielectric material

material 17, as shown in FIG. 5.

Detailed Description Text - DETX (20):
FIG. 6 shows a schematic cross-sectional view of another magnetic device having a multiple **granular** layer structure according to a modification of the second embodiment of the present invention.

Detailed Description Text - DETX (58):
The magnetic device of the present embodiment comprises a first metal layer 11 (which includes a first Au layer/a Fe layer/a first Co.sub.8 Pt.sub.2 layer), a first dielectric layer 12 (which includes a first SiO.sub.2 layer), a **granular** layer 16 (which includes a second Co.sub.8 Pt.sub.2 layer/a SiO.sub.2 material layer having Co.sub.8 Pt.sub.2 grains in its layer), a second dielectric layer 14 (which includes a second SiO.sub.2 layer), and a second metal layer 15 (which includes a third Co.sub.8 Pt.sub.2 layer/a Co.sub.9 Fe layer/a second Au layer), and also includes two tunnel junctions, as shown in FIG. 4, and has 100.times.100 square micron area. The structure is formed by the following steps.

Detailed Description Text - DETX (94):
FIG. 28a shows a schematic diagram of a magnetic device affording to a twelfth embodiment. FIG. 28b is a schematic energy band diagram at two ferromagnetic tunnel junctions of the magnetic device and showing spin directions of the magnetic device of FIG. 28a according to the twelfth embodiment of the present invention. The device has a spin dependent resonance effect at room temperature. The device comprises a first electrode 51, a **granular** ferromagnetic layer 52, a nonmagnetic second electrode 53, and a bias electrode 56. The first electrode 51, the **granular** ferromagnetic layer 52, and the second electrode 53 is laminated as shown in FIG. 28a. The **granular** ferromagnetic layer 52 comprises a plurality of ferromagnetic grains

55
scattered in a nonmagnetic material 54. The **granular** layer 52 has a finite coercive force and has ferromagnetism rather than paramagnetism. Two tunnel junctions are formed between the grains 55 and each of the electrodes 51, 53 via part of the nonmagnetic material 54. The electrode 51 preferably is formed of ferromagnetic material, and nonmagnetic material of the second electrode 53 may be substituted with ferromagnetic material. An insulator layer which is thin enough to let the tunnel current path through itself may be interposed between one of the electrodes 51, 53 and the **granular** ferromagnetic layer 52.

Detailed Description Text - DETX (95):

When a positive (negative) voltage Vbe is applied to the **granular** ferromagnetic layer 52 through the first electrode 51 and the electrode 56 and negative (positive) voltage Vcb is also applied through the electrode 56 and the second electrode 13, as shown in FIG. 28a, the discrete energy levels are formed in the grain 55. The grain 55 has a sufficiently small size and is surrounded by the nonmagnetic material 54, as shown in FIG. 28b, by the effect of electrostatic energy Ec originated by the Coulomb Blockade effect. The energy Ec is expressed by e2/2C, where e is electric charge of electron and C is capacity of the grain. In this manner, the resonance tunnel levels are obtained and the magnetoresistance becomes small. When the discrete level is controlled by the electrode 56 to be moved from the resonance state, the magnetoresistance becomes large by the Coulomb Blockade effect. A large MR amplitude is obtained by reversing the magnetization direction of the ferromagnetic layer 51 to be parallel/antiparallel in relation with the magnetization direction of the fixed magnetization direction of the layer 52.

Detailed Description Text - DETX (97):

FIG. 29 is a schematic cross-sectional view showing a modified

magnetic
device according to the twelfth embodiment of the present invention. The
relative angle between the first electrode 51 and the ferromagnetic **granular**
layer 52 may be measured as described in the eleventh embodiment. The magnetic
device of this embodiment can be modified to include an electrode 57 for
applying voltage to the **granular** layer 52, as shown in FIG. 29. The electrode
57 applies gate voltage Vg to the **granular** layer 52. The tunnel current flows
the **granular** layer 52 by applying voltage between the first electrode 51 and
the second electrode 53. The discrete energy level of the grains 55 can be
controlled by Vg to be off or in the resonance state. Reference numeral 58 is
a substrate and reference numeral 59 is a nonmagnetic insulator layer in FIG.
29.

Detailed Description Text - DETX (99):
The device of this embodiment may include a plurality of **granular** layers 52
or a stacked film comprising both a **granular** layer and a ferromagnetic layer.

Detailed Description Text - DETX (100):
The **granular** layer 52 may have a finite coercive force and have less
saturation magnetization than a conventional **granular** layer. The electric
resistance of the **granular** layer 52 is smaller than that of the junction that
includes the dielectric later 44 and can be preferably controlled by the grain
volume packed ratio in the **granular** layer 52, the current path in the **granular**
layer 52, the grain size, or the scattered material.

Detailed Description Text - DETX (101):
Co, CoPt alloy, FePt alloy, or an alloy comprising a transition metal and a
rare earth metal may be chosen for their large magnetic anisotropy so that the
granular layer 52 has a finite coercive force. The grains 15 may preferably be
arranged to be one or two layers so as to form a uniform tunnel

barrier.

Detailed Description Text - DETX (102):
A hard magnetic layer for applying magnetic fields may be introduced adjacent to opposite ends of a relatively small coercive force **granular** layer. An antiferromagnetic layer may also be introduced to fix the magnetization direction of the small coercive force **granular** layer 52.

Detailed Description Text - DETX (105):
Ferromagnetic materials of the first electrode 51 preferably have a coercive force difference between the **granular** layer 52 and may be chosen from well-known ferromagnetic materials, such as identified in the above embodiment.

Detailed Description Text - DETX (107):
The ferromagnetic material for the second electrode 53 may be chosen so as to have coercive force difference from the **granular** layer 52. The first electrode 51 may be substituted with a stacked film structure comprising ferromagnetic layers and nonmagnetic layers, each interposed between the ferromagnetic layers so that the ferromagnetic layer is antiparallel in relation to the adjacent ferromagnetic layer by the effect of ferromagnetic coupling or static magnetic coupling. The stacked structure is preferable because it does not produce stray fields. The first ferromagnetic layer 51 may be substituted with another stacked structure comprising ferromagnetic layers and semiconductor layers, each interposed between the ferromagnetic layers. The spin direction of the second modification may be turned around and recorded by annealing or lighting the stacked film without applying bias magnetic fields to the film. The semiconductor material may be chosen from the group consisting of B20 structure FeSi alloy, .beta.-FeSi.sub.2, and GaAs.

Detailed Description Text - DETX (108):
The **granular** layer 52 and the first electrode 51 may be applied unidirectional magnetic anisotropy in its film plane so as to show a quick turn

of the magnetization and stable magnetization. The unidirectional magnetic
anisotropy is preferable for a magnetic memory device. The thickness of the
granular layer 52 and the first electrode 51 may be in the range of 0.5 nm to
100 nm. The thickness of the **granular** layer 52 may preferably be uniform and
be 50 nm or less to obtain fine tunnel conduction.

Detailed Description Text - DETX (110):
A conductive layer 62, a pair of ferromagnetic layers 63 (63a, 63b), a
granular layer 64, and a metal layer (gate electrode) 65 are formed in this
order on a substrate 21 so that the **granular** layer 64 is interposed between the
ferromagnetic layer 63a and the gate electrode 66, as shown in FIG. 31. The
ferromagnetic layer 63b applies magnetic bias fields to the ferromagnetic layer
63a so as to lower the coercive force of the ferromagnetic layer 63a and may be
omitted when the coercive force of the ferromagnetic layer 63a is small enough.
The conductive layer 62 may be used to change the magnetization direction of
the ferromagnetic layers 63 by current flow. The **granular** layer 64 receives a
voltage bias and is coupled to two pairs of electrodes 66, 67 and receives
current flow through the electrodes 66, as shown in FIG. 31. An insulator
layer 68 is interposed to insulate the electrode 66 and the ferromagnetic layer
63a, as shown in FIG. 31. The device may be covered with an insulator
protection layer 69, as shown in FIG. 31. One electrode of the pairs 66, 67
may be omitted.

Detailed Description Text - DETX (111):
The grains in the **granular** layer 64 are small enough and the discrete energy
levels are formed in the **granular** layer 64 by electrostatic energy of the
Coulomb Blockade effect. A tunnel current starts to flow by applying a voltage
between one of the pair of electrodes 66 and one of the pair of electrodes 67

and the discrete energy level of the **granular** layer 64 may be controlled by the gate electrode 65.

Detailed Description Text - DETX (112):

A large MR amplitude may be obtained when the discrete energy level of the **granular** layer 64 may be controlled by the gate electrode 65 to be different from the energy level of the conduction electron in the ferromagnetic layers 63. On the other hand, a small magnetic resistance may be obtained by a resonant tunneling effect, which appears when the discrete energy level of the **granular** layer may be substantially the same as that of the conduction electron of the layers 63. Therefore, the spin direction of the **granular** layer 64 may be sensed by applying a bias voltage and without applying outer magnetic fields. The spin direction of the ferromagnetic layers 63 turns around by applied magnetic fields produced by current flow in the conductive layer 62, as shown in FIG. 31.

Detailed Description Text - DETX (114):

The main surface of the substrate 21 may be oxidized by the thermal annealing method beforehand. The conductive layer 62 may comprise Cu and be formed on the main surface of the substrate 21. A 20 nm Fe layer (the ferromagnetic layer 63b) and a 10 nm Co.sub.80 Pt.sub.20 (the ferromagnetic layer 63a) are formed above the Cu layer 62. The 10 nm **granular** layer 64 is formed on the ferromagnetic layer 63a simultaneously using Co.sub.80 Pt.sub.20 alloy and SiO.sub.2 targets of 2 m Torr Ar gas pressure and 400 W substrate bias. The obtained **granular** layer is observed by Transmittance Electron Microscopy (TEM) and has Co.sub.80 Pt.sub.20 alloy grains layered in a SiO.sub.2 material. The total amount of the

Detailed Description Text - DETX (115):

grains in the layer is about 50%. The grain size is about 5 nm

and the interval between grains is about 1.5 nm. The coercive force of the **granular** layer 64 is about 600 Oe and shows clear hysteresis without super-paramagnetism.

Detailed Description Text - DETX (116):

FIG. 33 shows a voltage (Vg)(mV)-collector current (Ic)(mA) characteristic of the spin transistor of the thirteenth embodiment. The collector current Ic is a tunnel current flowing through the **granular** layer 64 to the ferromagnetic layer by applying voltage between electrodes 66, 67 and bias voltage Vg to the gate electrode 65. The spin directions of the ferromagnetic layers 63 are changed by magnetic fields of current flow through the conductive layer 62. FIG. 33 shows parallel spin direction state and shows a rapid increase of Ic by occurrence of a resonant tunnel current at around 10 mV.

Detailed Description Text - DETX (117):

FIG. 34 shows a change of Ic as resistance amplitude. The MR amplitude (.DELTA.R/Rs where Rs is resistance under **saturation magnetization** fields) when Vg=0 is large enough as 45%. On the other hand, the MR amplitude when Vg=11 mV is 15%.

Detailed Description Text - DETX (119):

A **granular** layer 64 is interposed between a pair of electrodes 70a, 70b and arranged in one plane, as shown in FIG. 32. The **granular** layer 64 and the pair of electrodes 70a, 70b are disposed on a substrate 21 with an insulator layer 71 interposed therebetween, as shown in FIG. 32. The electrode 70a may be a ferromagnetic layer. An electrode (gate electrode) 73 for applying a bias voltage between the substrate 21 and itself is disposed above the **granular** layer 64 with an insulator layer 72 interposed therebetween, as shown in FIG. 32. The gate voltage biasing method of this device is similar to that of a Field Effect Transistor.

Detailed Description Text - DETX (120):

The discrete energy level of the **granular** layer 64 is shifted to be different from that of the conduction electron of the electrode 70a by applying a bias voltage from the electrode 73 and then large tunnel current depending on spin directions of the ferromagnetic layer 70a and the **granular** layer 64 flows. The spin direction of one of the ferromagnetic layer 70a and the **granular** layer 64 having less coercive force than the other layer may be turned around. The spin direction of the ferromagnetic layer 30a may be reversed by current flow in the conductive layer 74 stacked and insulated from the ferromagnetic layer 30a by an insulator layer 75.

Detailed Description Text - DETX (121):

The discrete energy level of the **granular** layer 64 may be controlled to be substantially equal to the conduction electron energy level of the electrode by the gate electrode 73.

Claims Text - CLTX (18):

14. A magnetic device, as set forth in claim 1, wherein the magnetic device has at least a 30% MR amplitude at room temperature, where the magnetoresistance amplitude is defined by .DELTA.R/Rs, where .DELTA.R is a resistance change of the device and Rs is a device resistance at **saturation magnetization** fields.